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Summary

Single-shell Tank Waste Management Area (WMA) T at the Hanford Site is located in the northern 200 West Area. WMA T contains twelve primary single-shell carbon steel tanks, four ancillary tanks, and their auxiliary equipment. The tank farm was constructed in 1943 and 1944. During operations, tanks received mixed waste from the processing of spent reactor fuel to recover plutonium as part of the Hanford Site's defense mission. The tank farm ceased operations in 1980 and is currently regulated as a *Resource Conservation and Recovery Act* (RCRA) Interim Status Facility.

WMA T was placed in RCRA Groundwater Quality Assessment in 1993 and has remained in that status because of indications that contaminants from within the waste management area are entering groundwater.

The water table is declining and groundwater flow directions have changed in the vicinity of WMA T since initiation of assessment monitoring in 1993. These changes are a result of the cessation of effluent discharge to ground in 1995. Seven new RCRA monitoring wells have been constructed since 1997 to meet the groundwater monitoring needs resulting from changing water levels and flow directions and to assess contamination in groundwater.

Evaluation of groundwater data indicates that no RCRA-regulated contaminants from WMA T have affected groundwater. However, the contaminant technetium-99, regulated by the *Atomic Energy Act*, forms a plume detected near the northeastern corner of WMA T. That plume has its origin from the WMA and is largely contained near the top of the aquifer. This zone appears to have relatively low permeability based on pumping data obtained during well development and hydrological testing. In about 1997, the groundwater flow direction began to change from toward the northeast to toward the east or slightly north of east and, since then, the existing plume has apparently been drifting in that direction. If the measured flow velocity of 0.029 m/d is representative of the aquifer in the area, the plume would have moved approximately 42 meters east of well 299-W11-27 since 1998 when flow directions became stable. The high concentrations of technetium-99 seen in well 299-W11-27 in 1998 have not reached well 299-W11-39, which is 23 meters east of well 299-W11-27. This suggests either a slower rate of movement for the technetium-99 plume in the area or the mass of the plume passed to the north of the well. If tank waste contaminants are restricted to a low permeability portion of the aquifer, the lateral extent of the contaminants may be relatively small due to slow contaminant movement.

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1.0 Introduction

This report presents the findings of continued groundwater quality assessment at Waste Management Area (WMA) T in the 200 West Area of the Hanford Site (Figure 1.1). This report covers January 1988 through December 2001.

1.1 Background

WMA T was placed in groundwater quality assessment monitoring status in 1993 (Caggiano and Chou 1993). An initial assessment report, based on the results of a first determination, was issued in February 1998 and concluded the waste management area was contributing to groundwater contamination (Hodges 1998). Thus, a continued assessment of the concentrations of contaminants and the rate of movement and extent of hazardous waste constituents is required [40 CFR 265.93(7)]. Accordingly, an assessment plan (Hodges and Chou 2001) was prepared to obtain the data needed to determine the rate and extent of contaminant migration and contaminant concentrations in the groundwater. Summary information on assessment results is included in quarterly reports to the Washington State Department of Ecology (Ecology) and annually, as required, in the groundwater monitoring annual reports, e.g., Hartman et al. 2002. A map showing WMA T, associated monitoring wells, and surrounding facilities is shown in Figure 1.2.

1.2 Scope

Only water quality data and hydrologic testing results obtained subsequent to the first assessment report are included in this report. Hydrogeology of the site, stratigraphy, waste site descriptions, and contaminant hydrology were described in the first assessment report (Hodges 1998) and in the updated assessment plan (Hodges and Chou 2001). Therefore, the scope of this report is limited to evaluation and interpretation of data acquired from

- seven new wells installed during 1998 through 2001
- groundwater sampling data collected during well drilling
- additional routine, quarterly sampling data collected from the existing network from January 1998 through December 2001.

Supporting information (e.g., drilling information and hydrologic testing data) for this report are available in the project files of the Hanford Groundwater Monitoring Project at Pacific Northwest National Laboratory (PNNL) and in the borehole data packages for the new wells that were drilled during the report period (Horton and Hodges 1999, 2001; Horton 2002).

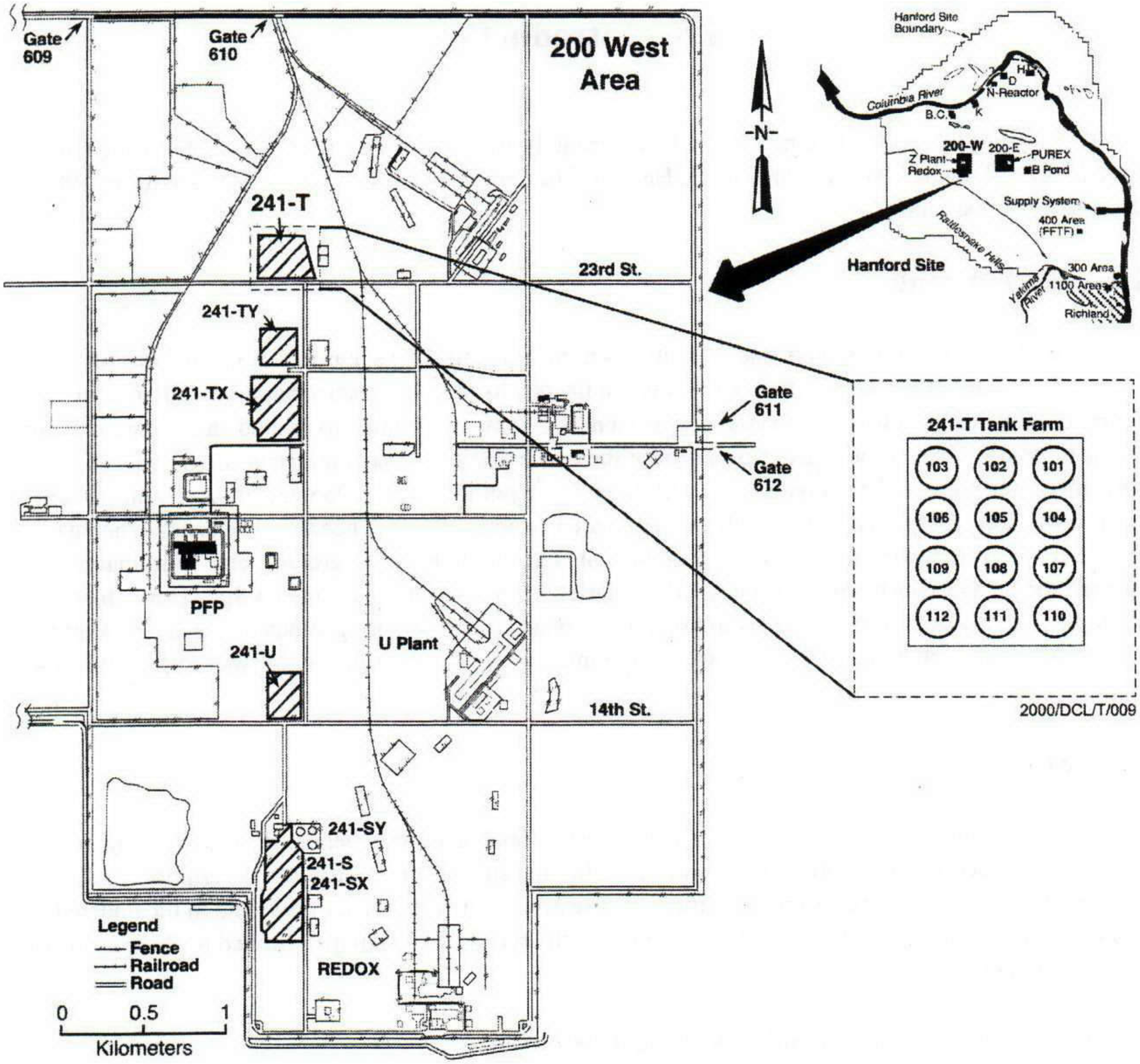

Figure 1.1. Location of Waste Management Area T on the Hanford Site

1.3 Basis for Groundwater Assessment at WMA T

Groundwater monitoring needs are principally defined by and directly support agreed-upon cleanup goals. Because such goals have not been developed and agreed to for the site in general and the WMA specifically, this section discusses only general guidelines for supporting the cleanup goals.

The following is based on the Hanford Cleanup, Constraints and Challenges Team strategy for groundwater protection, monitoring and remediation. This strategy provides a common, sitewide

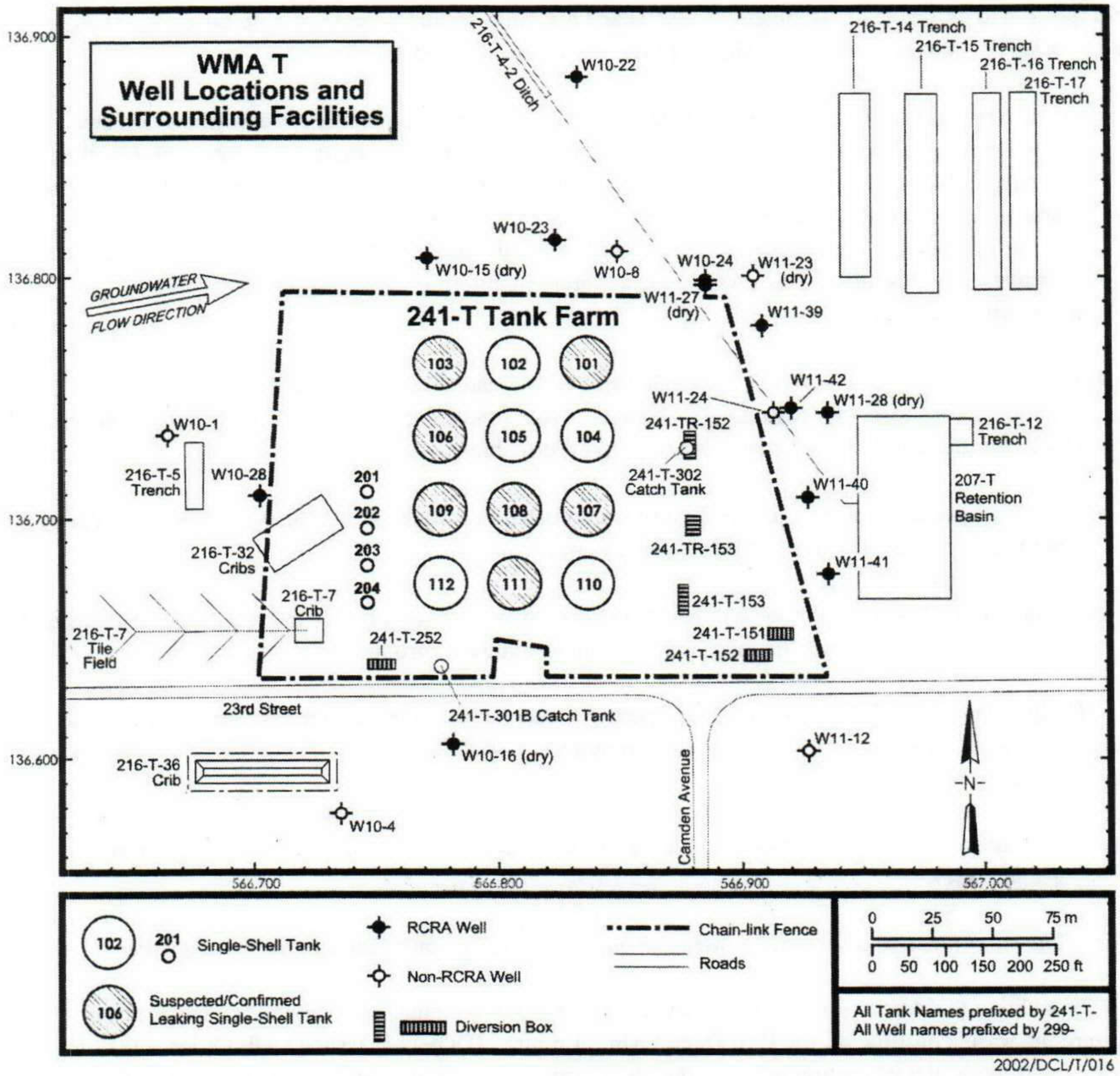

Figure 1.2. Waste Management Area T, Surrounding Facilities, and Monitoring Well Locations. Well 299-W11-7 is located about 350 meters east of the southern part of the WMA and Well 299-W11-30 is located about 300 meters east of the northern part of the WMA.

perspective to guide the development of assessment activities for individual operable units and when appropriate, groups of waste sites. Guiding principles are summarized below:

- When a new plume/contamination is discovered within an existing plume, assessment of the new plume/contamination should tie with the on-going assessment of the existing plume as long as the cleanup goals/objectives of both are the same. For other plumes, assessment actions will be undertaken once contaminant concentrations are detected in groundwater above an agreed to threshold. Whenever possible, predictions of future conditions with reliable estimates or known inventory information will be utilized as a tool to locate future monitoring wells and determine future monitoring requirements.

- Assessment will be focused on sites where there is adequate data to indicate sufficient mass of contaminant is present to leave the core zone at concentrations above the maximum concentration level, or significantly impact groundwater or the Columbia River.

- If contamination from an operating facility is observed, an evaluation will be performed to identify what needs to be done to correct problems at source.

- Predictions of future conditions will be used to establish the thresholds for triggering assessments and identifying the mass of contaminant that constitutes a threat to groundwater degradation.

Hodges and Chou (2001) described the objectives and general approach for assessment of groundwater quality at WMA T. Those objectives, as required by 40 CFR 265.93 (d) and WAC 173-303-400, are to determine

(i) The rate and extent of migration of the hazardous waste or hazardous waste constituents in the groundwater

(ii) The concentration of hazardous waste or hazardous waste constituents in the groundwater

In addition to the requirements of the RCRA implementing regulations that govern dangerous or hazardous waste constituents, the U.S. Department of Energy (DOE) has issued DOE Order 5400.1 to ensure a groundwater protection program that demonstrates compliance with all federal, state, and local laws and regulations including the *Atomic Energy Act*. The objectives of groundwater monitoring under DOE Order 5400.1 are

(i) Obtain data for the purpose of determining baseline conditions of groundwater quality

(ii) Demonstrate compliance with and implementation of all applicable regulations and DOE Orders

(iii) Provide data to permit the early detection of groundwater pollution or contamination

(iv) Identify existing and potential groundwater contamination sources and maintain surveillance of those sources

To this end, this report includes discussions of both RCRA-regulated dangerous-waste constituents and non-RCRA-regulated constituents, including radionuclides. The radionuclide contaminants are assessed under the *Atomic Energy Act* and can also provide information that helps determine the source and migration of dangerous waste constituents.

The assessment work done at WMA T during reporting period to meet these objectives was described by Hodges (2001). The work included (1) installation of new wells to complete the monitoring well network in response to changing flow directions and declining water levels, (2) hydraulic testing of the new wells for determination of aquifer properties and groundwater flow rate, and (3) sampling the new wells to determine the vertical and lateral extent of contamination.

1.4 Report Organization

Organization of this report is based on the objectives for the continuing assessment, which are to determine the rate and extent of migration and the concentration of groundwater contamination. Accordingly, Chapter 2 describes the groundwater monitoring network, particularly salient information gathered from installation of new wells. Chapter 3 discusses the rate of groundwater movement and direction of flow based on hydrologic data acquired during the reporting period. Chapter 4 discusses the spatial and vertical extents of contamination, contaminant concentration, and contaminant types based on new observations made during drilling of new monitoring wells for this assessment. Chapter 4 provides an assessment of the adequacy of the monitoring well network to detect contaminants originating from within the WMA. Chapter 5 provides information on the highest contaminant concentrations found at the WMA. Chapter 6 updates the conceptual model for WMA T with interpretations of data collected during the reporting period. Chapter 7 presents conclusions regarding the rate and extent of contaminant migration, possible source areas, and the likelihood of detecting groundwater contamination that could arise from this WMA in the future.

2.0 Monitoring Well Network Evaluation

The groundwater monitoring network at WMA T has required continued modification, both because of a declining water table and because of changing groundwater flow directions. The locations of the RCRA monitoring wells and non-RCRA wells used to supplement the groundwater quality assessment at the WMA T are shown in Figure 1.2.

2.1 Existing Network

All four of the original RCRA wells at WMA T (299-W10-15, 299-W10-16, 299-W11-27, and 299-W11-28) are dry as a result of the declining water table. In 2001, the last of the original wells, 299-11-28, could no longer be sampled.

The current groundwater monitoring network at WMA T consists of 14 wells. Five of these wells are older, non-RCRA wells. Well 299-W10-1 has been used as an upgradient well since flow directions shifted from a northward direction toward the east. It is an older well, with a long perforated interval. A new upgradient well (299-W10-28) was drilled in 2001. Well 299-W10-1 will continue to be sampled throughout 2002 and then, after continuity in analytical results are established between the two wells, 299-W10-1 will be dropped from the routine quarterly sampling schedule.

One non-RCRA well, 299-W10-8, is currently used to fill a gap on the north side of WMA T between two newer RCRA wells. Two older non-RCRA wells, 299-W10-4 and 299-W11-12, are south of WMA T. These wells were used as upgradient wells before groundwater flow changed from northerly to easterly. These wells still are used to monitor regional contaminant plumes impinging on the WMA. Finally, one older non-RCRA well, 299-W11-7, is located about 350 meters east of the southern part of the WMA and is used as a distant, downgradient well.

Two existing RCRA compliant wells, 299-W10-22 and 299-W11-30, are used as downgradient, distant wells. Well 299-W11-30 is located about 300 meters east of the northern part of the WMA. Well 299-W10-22 is located north of the WMA and is now situated more lateral than downgradient to the WMA with respect to groundwater flow direction.

Finally, seven new wells were drilled at WMA T and added to the monitoring network since 1997. These wells are discussed in the following section.

The groundwater monitoring network at WMA T is based on the current understanding of subsurface conditions. The initial network was designed based on professional judgment. Since the beginning of declining water levels in the area, the locations of wells were evaluated using a model (MEMO, Wilson et al. 1992). This provided an initial basis for the spacing and locations of wells. These wells have been effective in detecting contamination and defining plume contours.

On the basis of observations at WMA T, Hodges (1998) and Hartman et al. (2000) postulated very narrow contaminant plumes and the need for a maximum spacing between wells of approximately 35 meters. The current well spacing on the downgradient side (east side) of WMA T ranges from 30 to 36 meters.

2.2 Description of New Wells

Details on the drilling and construction of the wells and on the geologic conditions encountered during drilling can be found in the borehole completion reports (Horton and Hodges 1999, 2001; Horton 2002).

Seven new RCRA wells have been drilled at WMA T since 1997. Four of these wells (299-W10-23, 299-W10-24, 299-W11-39, and 299-W11-42) were drilled as replacements for existing, downgradient wells. Two of the new wells (299-W11-40 and 299-W11-41) were drilled to provide downgradient coverage needed because of changes in the direction of groundwater flow. The last new well (299-W10-28) was installed in 2001 as a new upgradient well. Table 2.1 lists the new wells and information about each well pertinent to hydrogeologic characteristics and the screened interval.

Some indications of relative aquifer permeability are found from information in the geologist's logs made during drilling. Of particular interest are textural descriptions that may indicate variations in permeability. In general, better sorted sediments and sediments with less fine-grained material are expected to be more permeable than poorly sorted sediments. For example, the description of the sediments through the screened interval of well 299-W10-23 notes a change from silty sandy gravel through most of the screened section, to sandy gravel near the bottom of the screen. Thus, the lowest part of the screened interval may be more permeable that the upper part. Similar lithologic changes are suggested by wireline geophysical surveys for the screened interval in well 299-W10-24 (Horton and Hodges 1999) and by the geologist's log and sieve analyses for well 299-W10-28 (Horton 2002).

Other potentially useful information can be gained by the geologists' comments. For example, the geologist noted that the method of removing drill cuttings in borehole 299-W11-39 changed from bailer to sand pump at a depth of 80.8 meters suggesting that the lower 2.5 meters of the screened interval is dominantly sand and may be more permeable than the silty sandy gravels of the upper part. Similarly, the geologist noted that borehole 299-W11-41 produced more water during drilling at below 80 to 82 meters. This corresponds to a change in texture from silty sandy gravel to sandy gravel and again suggests the possibility of a more permeable portion of the aquifer in the lower part of the screened interval. Although these types of observations are subjective, they are valuable clues to decipher aquifer properties.

Although not a controlled hydrologic test, the amount of drawdown during well development gives an indication of the relative permeability and hydraulic conductivity of the screened interval, or at least of some zone within the screened interval. These data are useful because well development is done routinely for all wells and, thus, is available for each well as opposed to the sparsity of other types of hydrologic test data. The pumping rate and amount of drawdown for all wells at WMA T drilled since 1997 are presented in Table 2.2. All wells in Table 2.2 are screened in the Ringold Formation hydrogeologic unit 5 (Williams et al. 2002). The variability in drawdown among the wells is large. The specific

Table 2.1. Construction and Lithologic Characteristics of the Screened Intervals of New Wells at Waste Management Area T[(a)]

Well[(b)]	Date Drilled	Drilling Method	Elevation of Brass Marker (m)[(c)]	Screen Interval (m)[(d)]	Pump Intake Depth (m)[(d)]	Total Drill Depth (m)[(d)]	Depth to Water (m)[(d,e)]	Comments
W10-23	08/98	Air Rotary	206.690	68.82 to 79.52	73.61	82.9	68.16	Silty sandy gravel in most of screened section grading to sand with no gravel in bottom 1.2 m of screened section[(f)]
W10-24	10/98	Air Rotary	208.978	71.00 to 81.70	75.56	131.8	70.53	Sandy gravel throughout the screened interval; [(f)] geophysical log suggest decrease in gravel at 72.5 m
W10-28	09/01	Cable Tool	206.100	68.64 to 79.30	71.31	85.34	68.73	Silty sandy gravel changing to silty sand at 76.8 m; [(f)] sieve analysis indicates sandy gravel at 79.8 m; geophysical logs indicate homogeneous lithology through screened interval
W11-39	09/00	Cable Tool	209.885	72.72 to 83.41	75.56	86.04	72.55	Silty sandy gravel changing to sandy gravel at 80.8 m[(f)] at which point driller switched from bailer to sand pump to remove material from borehole[(f)]
W11-40	09/00	Cable Tool	209.696	72.57 to 83.25	75.47	85.34	72.25	Sandy gravel throughout screen interval[(f)] supported by sieve analyses from 74, 78, and 83 m
W11-41	08/00	Air Rotary	209.667	72.15 to 82.81	74.42	85.34	72.28	Sandy gravel from top of screen to 75 m; silty sandy gravel from 75 to 82.3 m; sandy gravel at bottom of screen; [(f)] geologist's log noted more water produced during drilling at 80.8 m.
W11-42	09/00	Air Rotary	210.179	72.47 to 82.83	75.86	85.34	72.44	Sandy gravel throughout screened interval, matrix binds the gravel to make drilling difficult at 78.3 m[(f)]

(a) Information on well construction is from Horton and Hodges 1999, 2001 and Horton 2002.
(b) All well names preceding by 229-.
(c) Elevation in meters above mean sea level.
(d) Depth in meters below the surface.
(e) Water level at time of well construction.
(f) Information from geologist's log or daily field report.

Table 2.2. Development Pumping Data for Wells Drilled at Waste Management Area T Since 1997

Well	Year Completed	Pumping Rate (L/min)	Drawdown (m)	Specific Capacity (L/min/m)
299-W10-23	1998	30.3	1.0	30
299-W10-24	1998	37.8	4.6	8
299-W10-28	2001	52 to 113	0.1	520 to 1130
299-W11-39	2000	40.5	6.0	7
299-W11-40	2000	60.6	2.3	26
299-W11-41	2000	94.6	1.5	63
299-W11-42	2000	94.6	0.4	240

capacity for each well also is shown in Table 2.2. The specific capacities were calculated from the pumping rate and drawdown measured during well development. The specific capacity is a measure of the yield of a well per unit of drawdown. Of particular note are the ranges of values in wells 299-W10-24, 299-W11-39, and 299-W11-42 all located along the northeastern edge of the WMA. Wells 299-W10-24 and 299-W11-39 have the lowest specific capacity and are both located at the northeast corner of the WMA. Well 299-W11-42 has very high specific capacity and is immediately south of well 299-W11-39. The large differences in specific capacities of these three wells and their close proximately to one another give an idea of the spatial scale of heterogeneity in lithologic properties of the upper part of the aquifer.

The sediments around the new upgradient well 299-W10-28 are also of note. Based on the drawdown information (0.1 meter of drawdown while pumping 52 to 113 L/m), the sediments appear to be very permeable. In addition, the scientist who performed a slug test in this well stated[1] that the well fully recovered to static equilibrium within 10 seconds of removing the slug rod.

[1] Personal communication to authors from Darrell Newcomer, Pacific Northwest National Laboratory.

3.0 Rate and Direction of Groundwater Flow

The rate of groundwater movement beneath WMA T is estimated from classical methods (Darcy equation) and from borehole tracer dilution tests. The groundwater flow rate indicates the maximum (conservative) flow rate for conservative contaminants, whose movement through the aquifer is not retarded by mechanisms such as sorption or reaction.

3.1 Flow Direction

The direction of groundwater flow at WMA T was estimated based on water-table elevations in the network monitoring wells. This approach assumes the aquifer is homogeneous. Because there is evidence that the aquifer is non-homogeneous, this limitation must be kept in mind when applying the gradient analysis approach to estimate flow direction. A general flow direction may be estimated over the WMA, but at any specific location, perturbations may occur in the local flow direction due to localized low or high permeability zones. Details of the changes in groundwater flow direction that have occurred since 1998 are presented in Hodges and Chou (2001). Prior to 1998, groundwater flow was toward the northeast.

Water-table elevations for the area around WMA T are illustrated in Figure 3.1, based on March and August 2001 water-level measurements. Contours on the water-table map indicate that general groundwater flow at WMA T is slightly north of east. Comparison of the current water-table map with the previous 1999 water-table map (Hartman et al. 2000) indicates that the flow direction and gradient are approximately unchanged over the two year period but that the water table has declined about 0.5 meter at WMA T.

Trend-surface analysis also has been applied to monitoring well water-level elevations at WMA T (Spane et al. 2001). Analysis of March 1999 water level data for WMA T indicated a flow direction of 5 degrees north of east at well 299-W10-24, in good agreement with flow directions inferred from the water-table map.

3.2 Borehole Tracer Dilution and Tracer Pumpback Testing

Borehole tracer dilution and tracer pumpback tests were conducted in one of the new RCRA monitoring wells at WMA T. These tests permitted some inferences about flow rate as well as aquifer homogeneity and effective porosity (Table 3.1). After introduction of a bromide tracer into the borehole, continuous measurements of the bromide concentrations were made using downhole bromide sensors and a data logger system. Six equally spaced probes were used to characterize the 10.7-meter screened interval in the well. This test allowed direct observation of the effect of lateral groundwater flow through the screened interval of the well, and thus, provided an indication of the variability of flow through the screened interval. Details of the test methods, computations, and the results are included in Spane et al. (2001).

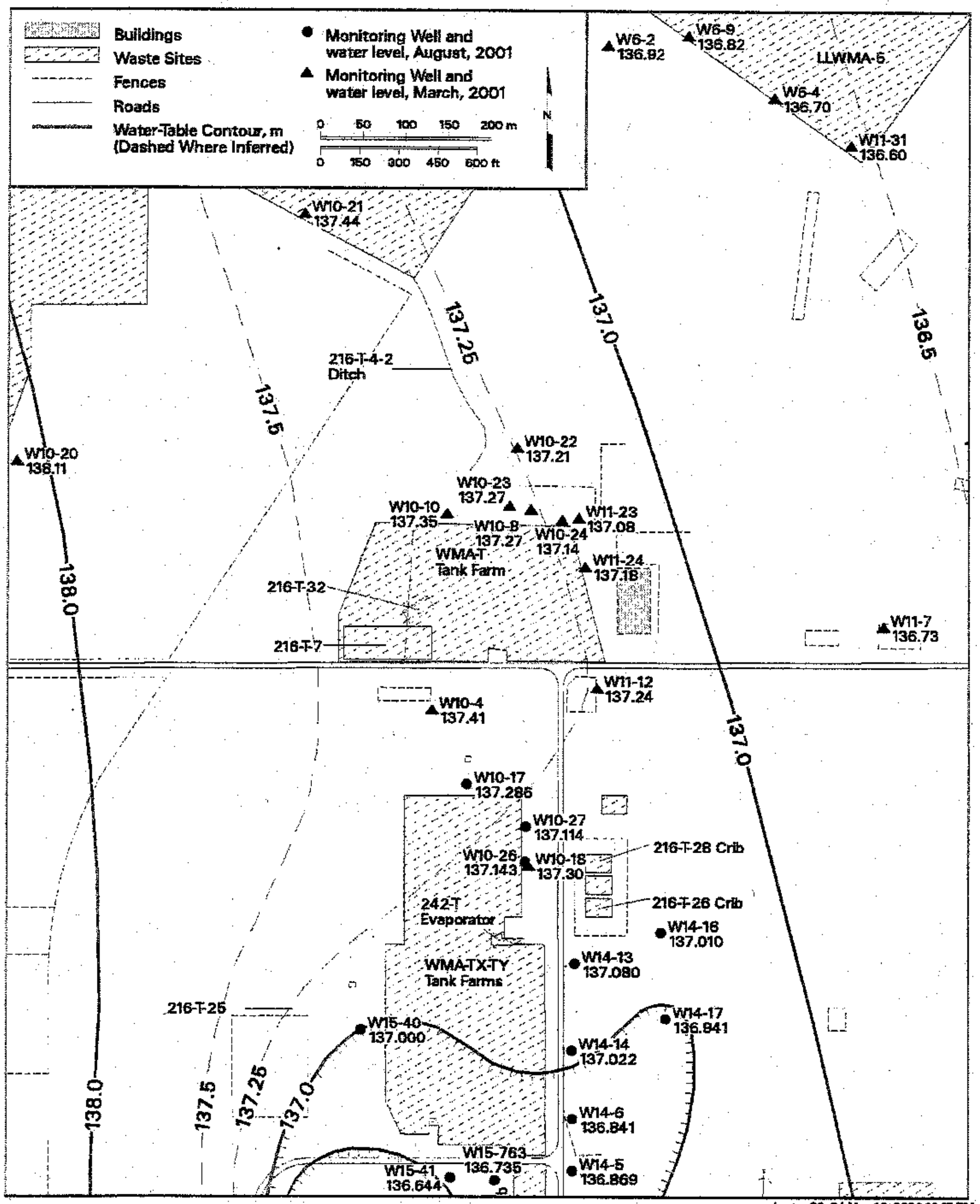

Figure 3.1. Water-Table Elevation Map for Waste Management Area T (March and August 2001 data)

Table 3.1. Results from Tracer-Dilution and Tracer-Pumpback Tests at Well 299-W10-24 at Waste Management Area T (Spane et al. 2001)

Well	Effective Porosity[a]	Groundwater Flow Velocity[a] (m/d)	Range of In-Well Flow Velocities[b] (m/d)	Average In-Well Flow Velocity[b] (m/d)
299-W10-24	0.072	0.029	0.009-0.017[c]	0.012

(a) Data from tracer pump back tests.
(b) Data from tracer dilution tests.
(c) Higher flow velocities in middle and lower portion of screened interval.

A significant feature of the hydrologic test data is the indication of higher hydraulic conductivity in the lower portions of the screened interval in well 299-W10-24. The data are shown in Table 3.2 (from Spane et al. 2001). Such hydraulic irregularities have been previously reported for the Ringold Formation at the north end of 200 West Area (Swanson 1994, pages 81 and 82; Lindsey and Mercer 1994, page 54). There is apparently a zone of lower hydraulic conductivity, probably a result of cementation or increased silt content in the upper part of the aquifer, along the eastern side of WMA T. This zone is highly variable in thickness and lateral extent, apparently encompassing most of the screened interval in well 299-W11-39, as suggested by the extreme drawdown during development pumping, and being relatively thin or non-existent in other wells in the area (e.g., well 299-W11-42 approximately 35 meters south of well 299-W11-39). The extent of this zone is important because it may exert significant control on the horizontal and vertical distribution of contaminants in this area.

Table 3.2. Tracer-Dilution Test Results for Well 299-W10-24 at Waste Management Area T (data from Spane et al. 2001)

Well Sensor/ Depth Setting, Below Ground Surface (m)	Well Sensor/ Depth Setting, Below Top of Water Table (m)	Calculated Well-Screen Flow Velocity (m/d)
72.8	2.3	0.009
74.7	4.2	0.009
76.5	6.0	0.13
78.3	7.8	0.17
80.2	9.7	0.13
82.0	11.5	*
Average		0.12

* No tracer-dilution analysis possible because of aberrant sensor readings.

3.3 Darcy Velocity

The Darcy equation for estimating velocity (v) requires measurements of hydraulic conductivity (K), effective porosity (n_e) and hydraulic gradient (i). The velocity is calculated from the following relationship:

$$v = Ki/n_e$$

For the WMA T assessment, new hydraulic conductivity data were obtained from slug tests and drawdown tests conducted in two new wells installed for this study. Effective porosity was determined using tracer drift and pumpback test methods. Hydraulic properties determined for this study are discussed in detail by Spane et al. (2001) and are presented in Tables 3.1 and 3.3. The water-table gradient was determined from data used to generate Figure 3.1.

Calculated Darcy velocities for data from wells 299-W10-23 and 299-W10-24 are shown in the right-hand column of Table 3.3. The measured velocity for well 299-W10-24 is shown in Table 3.1. The calculated Darcy velocity for well 299-W10-24 is in good agreement with the measured velocity.

Table 3.3. Hydraulic Properties from Slug and Constant Rate Pumping Tests and Calculated Darcy Velocities at Two New Wells at Waste Management Area T

Well	WMA	Hydraulic[(a,b)] Conductivity (m/d)	Hydraulic[(a,c)] Conductivity (m/d)	Transmissivity[(a,c)] (m^2/d)	Specific[(a,c)] Yield	Calculated Flow Velocity (m/d)
299-W10-23	T	1.62-2.35	-	-	-	0.024[(d)]
299-W10-24	T	1.04-1.68	1.22	66	0.11	0.023[(e)]

(a) Data from Spane et al. (2001).
(b) Slug test data.
(c) Constant rate pumping test data.
(d) Estimated using maximum hydraulic conductivity value, a gradient of 0.001(from Figure 3.1) and effective porosity values of 0.1
(e) Estimated using maximum hydraulic conductivity value, a gradient of 0.001, and effective porosity value from Table 3.1.

4.0 Extent of Contamination

This section presents discussions on the vertical and lateral extents of contamination at WMA T. Both RCRA-regulated dangerous-waste constituents and non-RCRA, *Atomic Energy Act*-regulated constituents are discussed. Consideration of all constituents simultaneously allows a more thorough understanding of subsurface conditions at the WMA.

Evaluation of the extent of contamination includes investigation of the type and concentration of contaminants in the groundwater, the depth distribution of contaminants, and the areal extent of contamination. Monitoring results from new and existing wells, results of depth sampling during installation of new RCRA groundwater monitoring wells, and the comparison of groundwater chemistry in old wells and their adjacent replacement wells, provides new insights into the occurrence and nature of groundwater contamination attributable to WMA T.

4.1 Depth Distribution

Determining the vertical extent of contaminants within the uppermost aquifer is part of RCRA groundwater quality assessments. Hodges and Chou (2001) included plans for discrete depth sampling of both new and old wells at WMA T; however, a sampling device under development was not available in time to provide data for this report. A variety of data, however, including discrete depth sampling during drilling and comparison of adjacent wells that sample different parts of the aquifer provide important information about the depth distribution of contaminants.

4.1.1 Conceptual Model Considerations

Contaminants entering the surface of a homogeneous unconfined aquifer can be dispersed downward as well as laterally and longitudinally. The degree of vertical spreading varies depending on the dispersivities, hydraulic gradients, driving force (local recharge or net drainage to the aquifer), and the density of the waste fluid relative to the density of the groundwater.

Departure from the theoretical depth distribution in a homogenous aquifer may occur depending on the nature of the aquifer host sediments. As noted in Chapters 2 and 3, there are indications of heterogeneities in the Ringold Formation in the study area. Limited data suggest that a local, relatively impermeable zone lies above a more permeable zone beneath the northeastern part of WMA T. In this case, contaminants entering the aquifer from the vadose zone in the northeastern part of WMA T may be restricted to the upper, less permeable part of the aquifer. Also, contaminants entering the WMA from upgradient sources may be diverted around or beneath this relatively impermeable part of the aquifer. An additional complicating feature is the potential existence of lateral preferential flow paths creating deviations in predicted horizontal plume extent and flow direction. These kinds of local variations in lithology have not been incorporated in solute transport models for 200 West Area. Therefore, the best alternative is direct observation of vertical and lateral variations found in field data. Field observations made during the reporting period help delineate the vertical and lateral extent of contamination at WMA T.

4.1.2 Vertical Distribution Data

Sampling at several discrete depths was conducted during drilling of well 299-W10-24 in 1998. Groundwater well 299-W10-24 was initially drilled through the lower mud unit of the Ringold Formation, with depth discrete sampling at approximately 15-meter intervals during drilling. The well was subsequently completed as a top-of-the-aquifer monitoring well with a 10.7-meter length of screen. Descriptions of the drilling and sampling of the well, as well as chemical results from the discrete level sampling, are presented in Horton and Hodges (1999) and are summarized in the following sections. In addition, samples of groundwater captured during air rotary drilling of wells 299-W11-42 and 299-W10-28 provide useful information concerning vertical contaminant gradients within the aquifer. Finally, comparison of chemical data in new wells with data for the wells they are replacing also provides data on chemical variations in the upper portion of the aquifer.

The information below concerning the depth distribution of contaminants is discussed relative to depth below the ground surface and not elevation. The difference in surface elevation among the new wells on the east, downgradient side of WMA T is about 1.2 meters. This difference is much less than the concentration gradients observed in the wells and should not greatly affect the conclusions. The difference between the elevation of the one upgradient well (299-W10-28) and the downgradient wells is greater and on the order of 4 meters with the downgradient well at lower elevation (see Table 2.1).

4.1.2.1 Depth Discrete Groundwater Sampling at Well 299-W10-24

Well 299-W10-24 was drilled through the lower mud unit of the Ringold Formation prior to being completed as a top-of-the-aquifer monitoring well. An air rotary drilling method was used to advance the borehole. When the desired depths were reached, the drill string was replaced with a submersible pump-and-packer assembly consisting of a 1.5-meter length of slotted PVC that served as a temporary screen. An inflatable packer was used to isolate standing water in the drive casing from the water pumped to the surface. Water was purged until indicator parameters (pH, specific conductance, and temperature) were stabilized. Purge volumes were on the order of 400 liters. The water samples were filtered in the field to remove particulates.

Results from the pump-and-packer sample depths are shown in Table 4.1. The maximum technetium-99 concentration occurs at the water table, whereas the maximum values for tritium, nitrate, and carbon tetrachloride were found more than 20 meters below the water table. Detectable contamination extended through the thickness of the unconfined aquifer and beneath the lower mud unit (54 to 55 meters below the water table). The results are plotted in Figure 4.1 and suggest stratification of contaminants in the aquifer at well 299-W10-24.

The shallowest two samples from well 299-W10-24 have relatively high technetium-99 concentrations. The most likely source for the technetium-99, which is regulated by the *Atomic Energy Act*, in these samples is WMA T. Concentrations of technetium-99 below 4.6 meters are in the range of the regional technetium-99 values and some, but not all, technetium-99 in those samples may be from WMA T.

Table 4.1. Discrete Depth Sampling Results from Well 299-W10-24

Depth Below Water Table (m)[a]	Specific Conductance (µS/cm)	Technetium-99 (pCi/L)	Tritium (pCi/L)	Nitrate (µg/L)	Carbon Tetrachloride (µg/L)
0.18[b]	866	13,000	7,380	120,000	100
4.6[c]	1,225	2,090	20,600	456,000	
16.85	1,338	358	29,600	531,000	490
30.75	1,156	374	26,700	443,000	1,600
46.33	889	212	19,500	349,000	760
52.15	891	156	21,700	301,000	360
60.96[d]	780	96	9,220	282,000	220

(a) Water table elevation is 138 meters above sea level.
(b) Kabis sample from well 299-W11-27.
(c) Sample from screened interval after well completion.
(d) Sample from below Ringold lower mud unit.

Several estimates of tank waste composition have been made based on knowledge of the chemical processes used to generate waste disposed to single-shell tanks and tank farm operations records (Agnew 1997, Jones et al. 2000). There is a high degree of uncertainty in these estimates because of uncertainties in the historical records. In 1994, Freeman-Pollard reported measured values for contaminants in vadose zone sediments from borehole 299-W10-196. (Borehole 299-W10-196 was drilled through the contaminated sediments from the tank leak associated with tank 241-T-106.) This report uses the Freeman-Pollard (1994) data for comparison with data from groundwater samples because they are laboratory measured values.

Table 4.2 shows the technetium-99/nitrate ratios in groundwater samples from well 299-W10-24 and in sediment samples from borehole 299-W10-196. Comparison of technetium-99/nitrate ratios from the two sources assumes there is no fractionation of technetium-99 and nitrate in the vadose zone or the groundwater.

The uppermost groundwater sample from well 299-W10-24 has a technetium-99/nitrate ratio somewhat lower than, but similar to, those measured in the sediment from borehole 299-W10-196. This supports the hypothesis that the technetium-99 and much of the nitrate in the upper part of well 299-W10-24 is from tank waste from WMA T. All of the deeper samples have ratios much smaller than any of the measured value ratios from borehole 299-W10-196.

The most likely source for relatively deep tritium, carbon tetrachloride, and much of the nitrate in well 299-W10-24 is past-practice disposal in cribs and trenches related to the tank farms and/or related to the Plutonium Finishing Plant operations. Groundwater migration in the vicinity of WMA T has had a complicated history of migration over the past 50 years as a result of changing patterns of surface water disposal. As a result, the direction of groundwater flow changed from toward the south to toward the north, and more recently to toward the east. These major shifts in flow direction very likely entrained

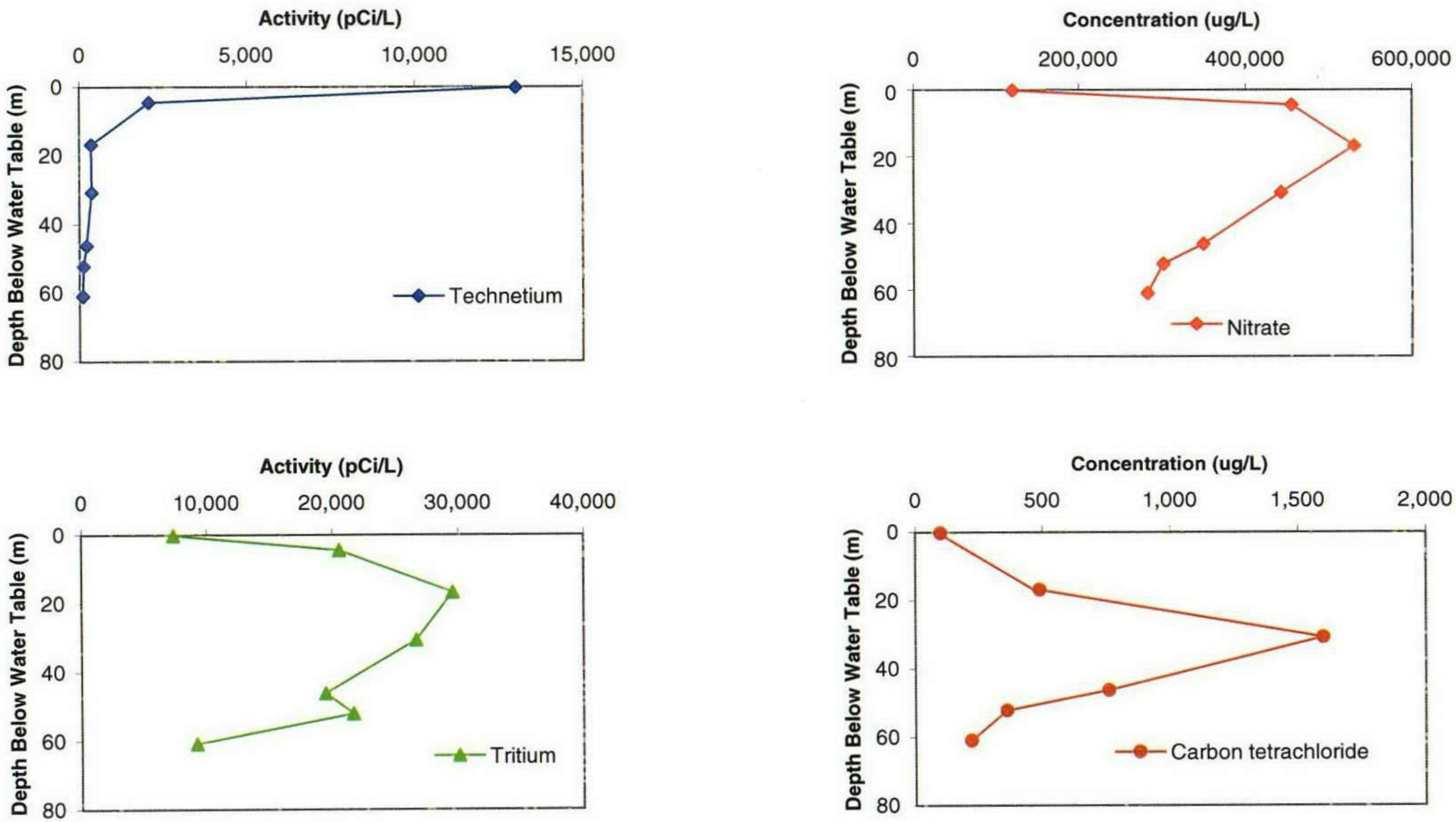

Figure 4.1. Depth Distribution of Key Contaminants, Well 299-W10-24, Waste Management Area T

Table 4.2. Technetium-99/Nitrate Ratios from Various Sources at Waste Management Area T

Sample	Tc-99 (pCi/L)	NO_3 (µg/L)	Tc-99/NO_3 (pCi/µg)
Well 299-W10-24[(a)]			
0.18	13,000	120,000	0.108
4.6	2,090	456,000	0.004
16.85	358	531,000	0.00067
30.75	374	443,000	0.00084
46.33	212	349,000	0.00061
52.15	156	301,000	0.00052
66.96	96	282,000	0.00034
Well 299-W10-196[(b)]			
13.2	48,214	230,194	0.20945
13.9	5,269	256,312	0.20558
16.1	31,316	242,146	0.12933
16.1	55,000	295,268	0.18627
18.2			
25.2	9,750	29,217	0.33371
27.7	38,889	109,342	0.35566
27.7	17,778	112,883	0.15749
29.2	120,000	422,317	0.28415
29.8	181,250	969,469	0.18696
30.5	109,091	597,618	0.18254
31.4	Not Available	Not Available	Not Available
33.2	282,353	4,426,800	0.06378
Well 299-W11-27[(c)]			
Feb 1997	21,700	45,500	0.477
May 1997	18,900	38,600	0.490
Aug 1997	16,000	36,500	0.438
Sept 1997	13,500	29,000	0.466
Nov 1997	15,200	30,400	0.500
Feb 1998	12,100	24,300	0.498
May 1998	10,500	97,000	0.108
Aug 1998	13,000	27,200	0.478
Mar 1999	6,000	16,300	0.368

(a) Data from depth discrete sampling during well drilling. Depths are in meters below the water table.
(b) Depths of samples from 299-W10-196 are meters below ground surface.
(c) Routine sample and analysis results from well 299-W11-27.

nitrate and carbon tetrachloride from the Plutonium Finishing Plant cribs and trenches, and tritium from cribs and trenches in north-central 200 West Area. Also, downgradient wells and wells that were downgradient during the prior flow regime have historical data showing regional tritium, nitrate, and chromium entering the area of WMA T.

4.1.2.2 Sampling During Drilling

Sampling of water brought to the surface during air rotary drilling can give an indication of vertical variations within the aquifer (Johnson and Chou 2001). During drilling in calendar years 2000 and 2001, limited groundwater sampling was completed during drilling at two wells in WMA T.

Well 299-W11-42. In September 2000, eight water samples were separated from airlifted slurry during the drilling of well 299-W11-42 (see Figure 1.2), a downgradient, point-of-compliance well east of WMA T. Six of the samples were collected from the geologist's grab samples as part of normal sampling. The two other samples were larger, approximately 1 liter, and were collected after casing additions. All samples were filtered and specific conductance was determined in the field. In addition, the two larger samples were analyzed for nitrate.

Analytical results as a function of depth below the water table are shown in Table 4.3. The most striking feature of the data is the sharp increase in specific conductance between 5.2 and 8.3 meters below the water table, and the difference in nitrate concentrations above and below this break. The depth of this break corresponds to the depth at which there is an apparent change from relatively low permeability above to higher permeability below (see Table 3.3 and associated discussion).

Table 4.3. Analytical Results for Groundwater Samples Taken During Drilling of Well 299-W11-42

Depth Below Surface (m)	Depth Below Water Table (m)	Specific Conductance (μS/cm)	Nitrate (μg/L)[(a)]
73.2	0.6	580	*
74.7	2.1	688	*
76.2	3.7	660	*
77.7	5.2	758	302,000
80.8	8.3	1,392	*
82.3	9.8	1,419	*
83.8	11.3	1,420	*
85.3	12.8	1,400	576,000

(a) Nitrate as NO_3^-. Analyzed by HACH cadmium reduction method (method 8039) using a DR/2010 portable spectrophotometer. Reagent blank corrected.
* Not determined.

Results from the routine groundwater sampling of this well since the time it was completed yield specific conductance values between 1,306 and 1,473 μS/cm and nitrate concentrations between 426,000 and 606,000 μg/L. These routine quarterly values are most similar to those obtained from samples deeper than 78 meters during drilling than they are to the shallowest samples. The water sampled from the screened interval in well 299-W11-42 (the upper 10.7 meters of the aquifer) represents an average along the length of the screen, with zones of higher hydraulic conductivity providing a proportionally greater percentage of the sample. Comparison of the analysis results from samples collected after drilling with the values obtained during drilling indicates that a high percentage of the water collected during routine sampling came from the bottom portion of the screened interval.

Technetium-99, regulated by the *Atomic Energy Act*, ranged from approximately 300 to 460 pCi/L in routine quarterly samples from well 299-W11-42 during the reporting period. Some of this technetium-99 may be from tank waste at WMA T, but these technetium-99 concentrations are within the high end of regional technetium-99 values and the technetium-99/nitrate ratios are low and similar to the deep ratios at well 299-W10-24. The contaminants in the deep samples at 299-W10-24 are hypothesized to be from mostly regional plumes and not from WMA T.

Well 299-10-28. In September and October 2001, two water samples were separated from airlifted slurry during the drilling of well 299-W10-28 (see Figure 1.2), an upgradient well west of WMA T. The samples were collected at 8.2 and 16.8 meters below the water table. The samples were transported to the laboratories in the Applied Geology and Geochemistry Group at the Pacific Northwest National Laboratory. In the laboratory, the samples were filtered and analyzed for specific conductivity and anions using the laboratory's standard operating procedures (AGG-SST-VZC)[1]. Analytical results from the two samples are shown in Tables 4.4 and 4.5.

Well 299-W10-28 is the new upgradient well in the monitoring network at WMA T. Thus, the concentrations shown in Tables 4.4 and 4.5 represent background concentrations entering the WMA. The depth distribution of nitrate in well 299-W10-28 is similar to that seen in well 299-W10-24 located

Table 4.4. Specific Conductance and pH for Samples from Well 299-W10-28

Depth Below the Water Table (m)	pH	Specific Conductance (μS/cm)
8.2	7.45	1,381
16.8	7.36	784

[1] AGG-SST-VZC. Applied Geology and Geochemistry Group Procedures for Single-Shell Tank Vadose Zone Characterization, Pacific Northwest National Laboratory, Richland, Washington.

Table 4.5. Anions in Samples from Well 299-W10-28

Depth Below the Water Table (m)	Fluoride	Chloride	Nitrite	Bromide	Nitrate	Sulfate	Phosphate	Carbonate
8.2	1,810	34,000	77,290	<1,000	562,420	51,810	<1,500	48,130
16.8	940	20,810	19,740	<1,000	274,700	40,620	<1,500	52,500
Note: All concentrations are reported in µg/L.								

downgradient of the WMA. However, the concentration gradient for nitrate seen in well 299-W10-28 does not mimic that seen in well 299-W11-42 (see Table 4.3). Unfortunately, comparatively deep samples were not obtained from well 299-W11-42, which may account for part of the difference. The available data illustrate the difficulty interpreting both vertical and lateral concentration gradients in an aquifer in heterogeneous sediment.

4.1.2.3 Replacement Well Comparisons

Replacement wells, when located immediately adjacent to the older wells, offer an opportunity to look for vertical variation within the upper part of the aquifer. Three well pairs near the northeastern corner of WMA T are discussed in the following paragraphs.

In each case discussed below, the old well and its replacement well are separated by several meters at most. In addition, in each case, the older well was last sampled when there was a fraction of a meter of water within the screened interval and the replacement well was sampled with a pump placed at least 3 meters below the water table within a 10.7-meter screened interval. Thus, the sample from the old well represents the top of the aquifer and the samples from the replacement well represent a weighted average over the length of the screened interval that includes deeper parts of the aquifer.

Wells 299-W11-27 and 299-W10-24. Wells 299-W11-27 and 299-W10-24 are about 3 meters apart and are located near the northeastern corner of WMA T. Well 299-W11-27, the well responsible for the WMA remaining in assessment, reached a peak concentration of 21,700 pCi/L in February 1997 for the constituent technetium-99, which is regulated by the *Atomic Energy Act*, and dropped to 6,000 pCi/L for the last sampling in March 1999 (Figure 4.2).

Discrete depth sampling during drilling of replacement well 299-W10-24 indicates that the water sampled during routine groundwater monitoring from that well is a mixture of high technetium-99 groundwater similar to the last samples from well 299-W11-27, and a high nitrate, low technetium-99 groundwater similar to the regional background (Hodges 1998) and to that found in the lower part of the aquifer at well 299-W10-24. Apparently high-nitrate, low-technetium-99 groundwater from the lower part of the screened interval is mixing with the groundwater contribution from the upper portion of the screened interval and dominates the groundwater chemistry in the well. This interpretation is consistent with tracer pump back tests, which indicate that the lower portion of the screened interval in well

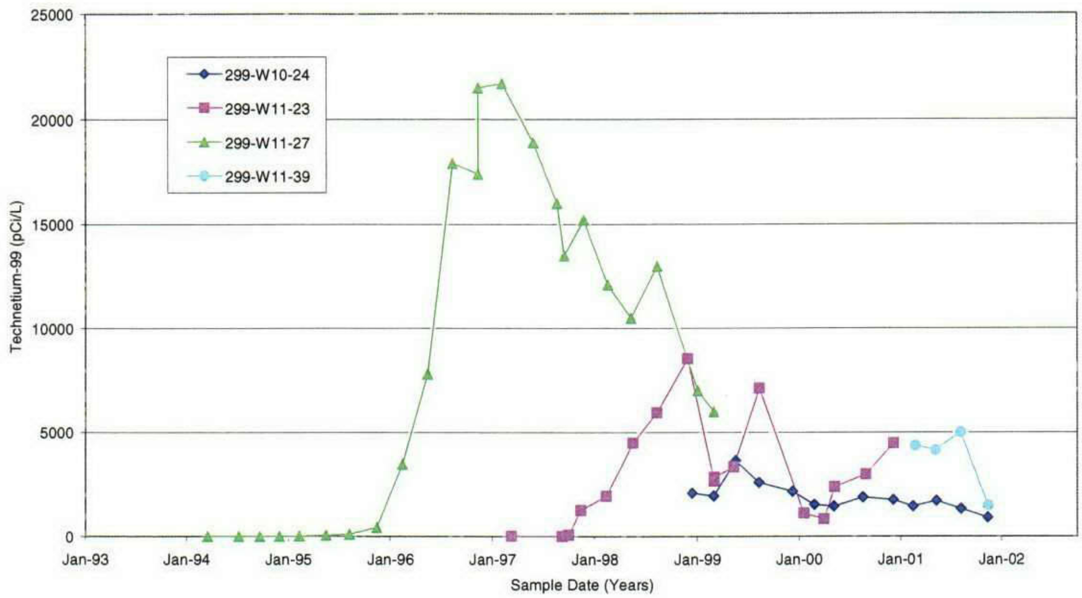

Figure 4.2. Technetium-99 Concentrations in Wells at Waste Management Area T

299-W10-24 is more permeable than the upper portion and, therefore, expected to yield a larger proportion of water to the routine, pumped samples. The situation in 299-W10-24 is similar to that indicated by the sampling-during-drilling results for nearby well 299-W11-42 which indicated higher nitrate concentrations at depth within the screened interval (see Table 4.3).

Technetium-99 and nitrate data from the last two years of sampling well 299-W11-27 are included in Table 4.2. After October 1997, the well was sampled by bailing dry twice, letting the well recover for 15 minutes, and then collecting the sample. The last samples were collected with less than 0.5 meter of water in the well (not in the screened interval) and represents the uppermost part of the aquifer at the time the water level passed the lower portion of the screened interval. The technetium-99/nitrate ratios for the last samples from well 299-W11-27 are greater than those of the samples collected from well 299-W10-24 and are somewhat higher than, but close to, those measured on sediments from well 299-W10-196 (Freeman-Pollard 1994).

The high technetium-99/nitrate ratios, as compared to those from wells 299-W10-24 and 299-W10-196, may be due to unusually high technetium-99 concentrations in the last samples from well 299-W11-27 because of fine particulates associated with sampling the bottom of the well. Turbidity in the samples from this well was extremely high after November 1997. Nevertheless, the data indicate that there may be more technetium-99 currently in the vadose zone slightly above the current water level than what is found in the groundwater during drilling of well 299-W10-24. As the high technetium-99 plume at the water table drops, technetium-99 is expected to remain as residual moisture in the vadose zone. If this is the case, contamination is expected to drain from the newly created vadose zone in this area into the groundwater for some time into the future.

Wells 299-W11-23 and 299-W11-39. Wells 299-W11-23 and 299-W11-39 are located near the northeastern corner of WMA T and are less than about 5 meters apart. Well 299-W11-23, a non-RCRA well, was the second well to intercept the technetium-99 plume at the northeastern corner of WMA T. Groundwater from replacement well 299-W11-39 is similar to the last sample from well 299-W11-23, with similar nitrate and technetium-99 levels (see Figure 4.2). The similarities in technetium-99 concentrations in the last samples from well 299-W11-23, and the routine pumped samples from replacement well 299-W11-39, suggest that technetium-99 is not restricted to the top of the aquifer in well 299-W11-39 as it is in well 299-W10-24, but occurs at significant levels throughout the screened interval of the well. Also, there is no apparent contribution from the deeper high nitrate groundwater found in well 299-W10-24.

The drawdown during well development of well 299-W11-39 was large relative to the other wells in this part of the WMA (see Table 2.2). This indicates that a portion of, or the entire screened interval in well 299-W11-39, has relatively low permeability. These observations suggest that high technetium-99 at WMA T is associated with relatively low permeability sediment at the top of the aquifer at wells 299-W10-24 and 299-W11-39.

Wells 299-W11-28 and 299-W11-42. Well 299-W11-28 is a RCRA well located on the eastern side of WMA T (see Figure 1.2). Well 299-W11-28 went dry in 2001. Its replacement well, 299-W11-42, is the well described in Section 4.1.2.2 that was sampled during air rotary drilling. The two wells are about 14 meters apart. Sampling during drilling of well 299-W11-42 indicated that the upper portion of the screened interval is characterized by relatively low specific conductance and low nitrate groundwater, whereas the lower portion of the screened interval is characterized by groundwater with higher specific conductance and high nitrate.

Figure 4.3 is a plot of nitrate concentrations in wells 299-W11-28 and 299-W11-42. Well 299-W11-28 was last sampled in February 2000, and the first routine sampling of well 299-W11-42 took place in December 2000, providing overlap in the sampling of the two wells. The concentration of nitrate in the December 2000 sample from well 299-W11-28 was about 266,000 μg/L. This represented the concentration of nitrate at the water table in December 2000. The sample taken from the replacement well in December 2000 contained about 588,000 μg/L. That sample represented the nitrate concentration throughout the upper 10 meters of the aquifer. The conclusion is that nitrate exists at higher concentrations deeper in the aquifer.

Chromium and Well Pairs. The RCRA-regulated dangerous-waste constituent chromium has exceeded the maximum contaminant level in each of the new wells (299-W10-24, 299-W11-39, and 299-W11-42) in each of the three well pairs discussed previously during routine, quarterly sampling since they were drilled. Figure 4.4 shows the chromium concentrations in the wells. Only data from filtered samples collected since 1997 are shown. For each well pair, chromium is higher in the replacement wells that sample at least some water from a point lower in the aquifer that the older well, which sampled only the upper part of the aquifer. These data show that chromium at WMA T is concentrated relatively deep in the unconfined aquifer. Also, the chromium concentration in well 299-W10-4, which is located south of the WMA, has been between 150 and 250 μg/L since 1997. This well samples water upgradient (but lateral to) the WMA. Thus, chromium contamination at the WMA T originates from a source upgradient of the WMA. However, some chromium contamination in samples with high *Atomic Energy*

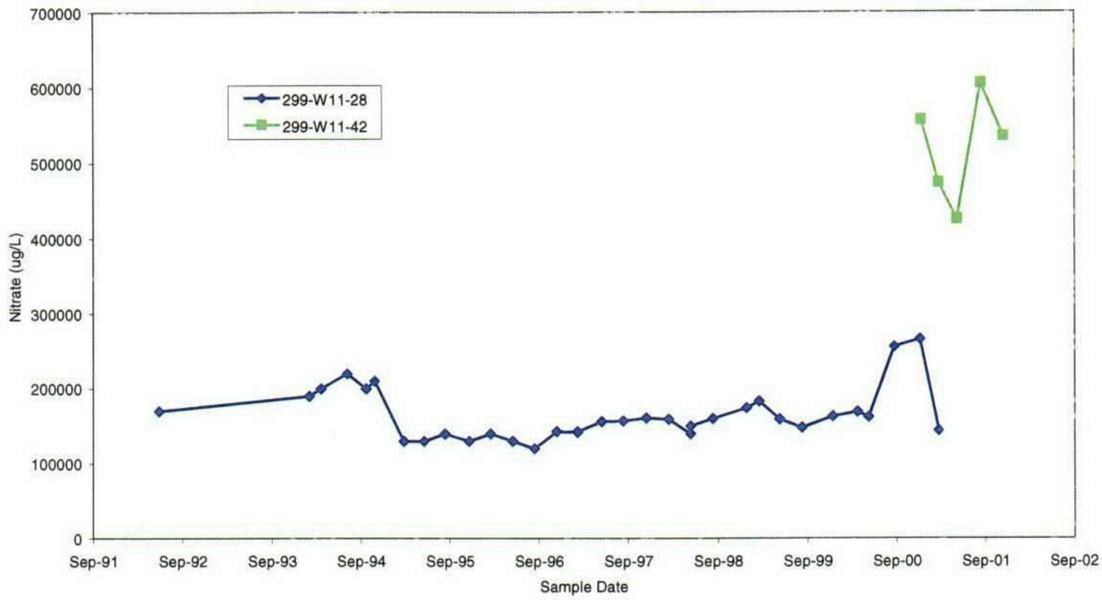

Figure 4.3. Nitrate Concentrations in Wells at Waste Management Area T

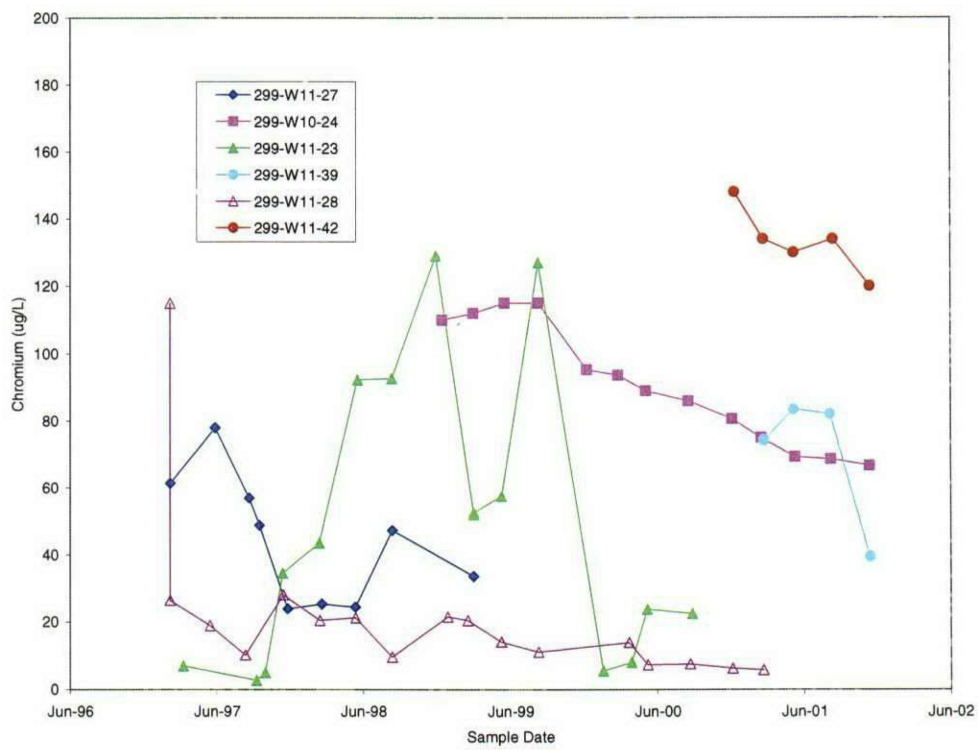

Figure 4.4. Chromium Concentrations in Well Pair 299-W11-27 and 299-W10-24, Well Pair 299-W11-23 and 299-W11-39, and Well Pair 299-W11-28 and 299-W11-42

Act-regulated technetium-99 may be from tank waste because the Hanford Derived Waste Model used by Agnew (1997) reports between 52 and 291 mg/L chromium in each single-shell tank in WMA T.

Summary. Data from sampling of groundwater during drilling operations and from adjacent well pairs, where the source of the samples are from different elevations within the aquifer, indicate that there is a vertical stratification of contaminants in the unconfined aquifer beneath WMA T.

At the northeastern corner of WMA T, *Atomic Energy Act*-regulated technetium-99 concentrations are highest in a less permeable zone near the water table than they are deeper in the aquifer. There, the distribution of contaminants and technetium-99/nitrate ratios suggest that WMA T may be the source for the shallow contamination. Tritium, nitrate, and carbon tetrachloride show highest concentrations in a more permeable zone about 20 meters below the water table in well 299-W10-24. RCRA-regulated chromium also appears to be more concentrated at depth within the aquifer. Most of these deeper contaminants did not originate from WMA T.

4.2 Geographic Distribution

It is difficult to accurately determine the areal distribution of contaminants originating from WMA T because of a number of factors. These include lack of knowledge of sources and groundwater contaminant concentrations within the WMA, changing groundwater flow directions, well coverage, and vertical heterogeneity in both contaminant distribution and hydraulic properties. The maximum concentrations of the major mobile tank waste contaminants for the current report period, January 1998 to December 2001, are summarized in Chapter 5.

Technetium-99, which is regulated by the *Atomic Energy Act*, is the best indicator of tank waste contamination, and occurs at low concentrations in groundwater across the area surrounding WMA T, along with elevated concentrations of sodium, nitrate, tritium, carbon tetrachloride, fluoride, and chromium in some wells. This background is a result of mixing of contaminants from a number of past waste-disposal activities including the disposal of tank waste, process water, and steam condensate at nearby cribs and trenches (Maxfield 1979; DOE/RL-91-61; RPP-5957), disposal of plutonium processing waste at cribs and trenches associated with the Plutonium Finishing Plant (DOE/RL-91-58), and leaks from single-shell tanks and transfer lines within the 241-T tank farm (Jones et al. 2000). Within this background groundwater, technetium-99 concentrations seldom exceed 400 pCi/L.

Well 299-W10-3 was located within WMA T and upgradient of the tanks, when it was sampled during decommissioning in July 2000. Analysis of groundwater from this well indicated high values (above maximum contaminant levels [MCL]) for the various background components, including sodium (514 mg/L) (there is no MCL for sodium but background values range from about 180 to 200 mg/L [DOE/RL-92-23]), nitrate (1,213 mg/L), tritium (23,600 pCi/L), fluoride (9,800 μg/L), and chromium (257 μg/L). Technetium-99 in this sample was only 409 pCi/L. This relatively low concentration for technetium-99 indicates little, or no, groundwater contribution at this well from the WMA T or the 216-T-5 trench, 216-T-7 crib, and the 216-T-32 crib that received tank waste (DOE/RL-91-61) upgradient of the WMA.

Technetium-99 began to increase in well 299-W11-27 in late 1995, coincident with the cessation of surface water disposal in the 200 West Area, reaching a peak level of 21,700 pCi/L in February 1997 (see Figure 4.2). Technetium-99 concentrations in well 299-W11-27 subsequently decreased to 6,000 pCi/L in March 1999. Comparison of tritium to technetium-99 ratios in well 299-W11-27 and other wells at the WMA indicate that the plume had arrived at well 299-W11-27 by the early 1990s, but was masked by dilution with infiltrating surface water (Hodges 1998). The most likely source of this water was the 60.9 centimeter, unpressurized, vitrified-clay water line located immediately adjacent to the well (Hodges 1998). The water line carried cooling and ventilation steam condensate, process cooling water, and evaporator condensate from the 207-T retention basin to the 216-T-4-2 ditch (DOE/RL-91-61). The subsequent decrease in technetium-99 in well 299-W11-27 since 1997 may have been a result of changing groundwater flow direction, and/or a declining water table; however, data from replacement well 299-W10-24 indicates an elevated concentration of technetium-99 in the upper portion of the aquifer.

Technetium-99 began to increase in well 299-W11-23 in November 1997, coincident with the change in groundwater flow to a more easterly direction. It increased to a high of 8,540 pCi/L in November 1998 (see Figure 4.2). Subsequently, technetium-99 values fluctuated between 7,110 and 840 pCi/L. The last sample from this well, taken in December 2000, indicated a technetium-99 concentration of 4,470 pCi/L. The most plausible explanation for the 1997 arrival of the contaminant plume at well 299-W11-23 is the change in groundwater flow direction. Under this scenario, a narrow contaminant plume, initially moved northeast across well 299-W11-27 but not across well 299-W11-23. Changing groundwater flow direction caused this plume to drift laterally across well 299-W11-23. Sampling of replacement well 299-W11-39 in 2001 detected technetium-99 concentrations between 4,160 and 5,010 pCi/L, indicating contamination of the upper portion of the aquifer at this well.

RCRA-regulated chromium, a co-contaminant at WMA T, may have resulted from two different sources: a regional chromium plume and WMA T. The highest chromium values found during the reporting period are in well 299-W10-4. Chromium in this well has increased from 172 μg/L in February 1999 to 225 μg/L at the end of 2001. Well 299-W10-4 was upgradient to WMA T until about 1997 when it became lateral to the WMA after the change in flow direction. Chromium in this well is from a regional chromium plume impinging on the WMA from upgradient.

Some of the chromium in well 299-W11-39 may be from tank waste as is suggested for the technetium-99 in this part of the aquifer. However, considering the relatively deep occurrence of chromium in the aquifer as identified in well pairs 299-W10-27 and 299-W11-24, 299-W11-28 and 299-W11-42, and 299-W11-27 and 299-W11-39 and considering the upgradient source for chromium seen in well 299-W10-4, most of the chromium in groundwater at WMA T probably originated outside of the WMA.

Sampling results indicate that technetium-99 and other tank waste constituents are within a low permeability zone in the upper portion of the aquifer in the vicinity of the northeastern corner of WMA T. The extent of the low permeability zone and to what degree the contaminants are entering the more permeable portions of the aquifer are unknown. Sampling results at well 299-W10-3 (which was located about 35 meters west of tank T-112 before it was decommissioned) indicate that the low permeability zone does not extend to the west across the tank farm; however, its extent to the north and east are uncertain.

A flow velocity of 0.029 m/d was measured for the screened interval of well 299-W10-24 (Spane et al. 2001). If this value is representative of the aquifer in the area, the plume would have moved approximately 42 meters east of well 299-W11-27 since 1998 when flow directions shifted. Well 299-W11-39 is 23 meters east of well 299-W11-27 and has technetium-99 concentrations about one-half of the concentrations seen in well 299-W11-27 in 1998 and about one-fourth of the maximum seen in 1995. This suggests a slower rate of movement for the technetium-99 plume in the area. This is supported by the drawdown data that suggests the well is screened in a low permeability zone. If tank waste contaminants are restricted to a low permeability portion of the aquifer, the lateral extent of the contaminants may be relatively small. However, it is also possible that lithologic heterogeneities have channeled much of the contamination away from the well.

5.0 Maximum Contaminant Concentrations

This section presents discussions on the maximum contaminant levels encountered at WMA T during the reporting period. Both RCRA-regulated dangerous-waste constituents and non-RCRA, *Atomic Energy Act*-regulated constituents are considered.

Table 5.1 shows the maximum concentrations detected for the primary constituents of concern for each well included in the monitoring network for the period January 1, 1998, to December 31, 2001. All wells that have been part of the monitoring network during the reporting period are included. Samples collected during drilling of new wells were not included in Table 5.1. Only filtered (0.45 μm) metal results are included in the summary. Results for anions, volatile organic compounds, and radionuclides are all based on unfiltered samples. The last column shows the highest maximum contaminant concentration (values in bold type) divided by the applicable maximum contaminant level or drinking water standard. This ratio is referred to as the relative hazard index for purposes of this report.

The highest relative hazard index at WMA T is for RCRA-regulated carbon tetrachloride. The high relative hazard index, a value of 320 (1,600 μg/L) for wells 299-W10-23 and 299-W11-41 is believed to be the result of disposal of carbon tetrachloride in cribs and trenches associated with the Plutonium Finishing Plant operations.

The highest hazard index for nitrate at WMA T is 29, resulting from a concentration of 1,290,000 μg/L in well 299-W10-4. This well is located south of the WMA T and the elevated nitrate detected by this well is part of a regional contaminant plume crossing the area, which in addition to nitrate contains elevated concentrations of carbon tetrachloride, chromium, tritium, and fluoride. The principal sources for the contaminants in this plume are probably waste disposal from the Plutonium Finishing Plant operations (carbon tetrachloride and nitrate) and from past-practice disposal of evaporator condensate and tank waste to ground.

The highest RCRA-regulated chromium at WMA T (relative hazard index of 5.1) is probably an anomaly. The same sample also had high iron and nickel, and concentrations of all three metals were higher than historical values for one quarter. The highest chromium concentration representing groundwater contamination at WMA T is 257 μg/L in well 299-W10-3 (now decommissioned). This well was within the WMA, but on the upgradient side, and the chromium detected in this well is probably part of the more regional plume detected by well 299-W10-4.

The highest hazard index for *Atomic Energy Act*-regulated technetium-99 at WMA T is 14.4, resulting from a technetium-99 level of 13,000 pCi/L in well 299-W11-27 (August 1998). The technetium-99 responsible for the highest hazard index is the contaminant most clearly linked to the WMA.

Nitrite has a maximum hazard index of 11 at WMA T because of a nitrite concentration of 36,100 μg/L in well 299-W11-24. Nitrite is generally low or absent in Hanford Site groundwater; however, it has been consistently high in well 299-W11-24 and in adjacent well 299-W11-28. These two

Table 5.1. Maximum Contaminant Concentrations for Groundwater Samples Collected from Waste Management Area T Network Wells (January 1998 to December 2001)

Analyte	MCL	W10-1[(a)]	W10-3[(a)]	W10-4[(a)]	W10-8	W10-12	W10-22[(b)]	W10-23	W10-24	W10-28[(a)]	W11-7[(b)]	W11-12	W11-23
Chromium[(c)] (µg/L)	100	34	257	193	136	99	60	153	115	66	12	47	129
^{99}Tc (pCi/L)	900	114	409	461	451	306	180	470	3,660	124	428	299	8,540
Nitrate (as NO_3) (µg/L)	45,000	189,000	1,210,000	**1,290,000**	478,000	379,000	152,000	584,000	474,000	1,120,000	207,000	134,000	104,000
Nitrite (µg/L)	3,300	<	<	<	<	<	<	<	759	1,840	<	<	526
Gross alpha (pCi/L)	15	2.9	10.4	8.7	3.0	3.4	5.9	5.1	<	<	<	3.6	12
Gross beta (pCi/L)	50	33.9	129	106	115	79.7	47.5	106	972	42	106	108	2,640
Tritium (pCi/L)	20,000	3,880	23,600	31,000	27,500	23,900	9,890	25,500	20,600	5,340	18,700	71,100	4,220
^{90}Sr (pCi/L)	8	NA	<	NA	NA	NA	NA	<	<	NA	NA	NA	<
^{137}Cs (pCi/L)	200	<	<	<	<	<	<	<	<	<	<	<	<
^{60}Co (pCi/L)	100	<	<	<	<	<	<	<	<	<	<	<	5
^{129}I (pCi/L)	1	<	<	<	<	<	<	<	<	NA	<	<	<
Iron[(a)] (µg/L)	300	255	<	74	111	201	83	79	73	82	67	232	61
Manganese[(a)] (µg/L)	50	5.4	9.8	18	4.6	9.0	4.5	15	31	97	5.9	20	33
Carbon tetrachloride (µg/L)	5	470	NA	1400	1100	1400	550	**1600**	NA	NA	1,000	NA	NA
Fluoride (µg/L)	4,000	411	**9,800**	5,250	3,200	5,000	530	3,800	4,400	2,100	1,150	510	310
pH	[6.5, 8.5]	[7.69, 7.94]	8.54[(d)]	[7.51, 8.13]	[7.88, 8.42]	[8.15, 8.31]	[7.90, 8.22]	[7.88, 8.35]	[7.75, 9.07]	7.72[(d)]	[7.76, 8.03	[801, 8.94]	[7.47, 8.18

Table 5.1. (contd)

Analyte	W11-24	W11-27	W11-28	W11-30[b]	W11-39	W11-40	W11-41	W11-42	Max[e]	Max/MCL
Chromium[c] (µg/L)	209	47	**509**	6	84	62	146	148	509	5.1
^{99}Tc (pCi/L)	293	**13,000**	548	193	5,010	297	532	464	13,000	14.4
Nitrate (as NO_3) (µg/L)	540,000	120,000	266,000	116,000	87,700	194,000	422,000	606,000	1,290,000	28.7
Nitrite (µg/L)	**36,100**	<	14,800	3,880	328	<	<	<	36,100	10.9
Gross alpha (pCi/L)	3.6	**98**	3.0	NA	<	4.3	3.4	<	98	6.6
Gross beta (pCi/L)	78.3	**5,380**	122	NA	1,420	70.8	111	115	5,380	108
Tritium (pCi/L)	28,200	7,860	44,500	**119,000**	5,830	26,600	32,500	14,500	119,000	6.0
^{90}Sr (pCi/L)	NA	NA	NA	NA	NA	NA	NA	NA	<	<
^{137}Cs (pCi/L)	<	-	<	NA	<	<	<	<	<	<
^{60}Co (pCi/L)	<	**19**	<	NA	<	<	<	<	19	0.2
^{129}I (pCi/L)	<	<	<	**3.9**	NA	<	NA	<	3.9	3.9
Iron[a] (µg/L)	**9,500**[f]	96	2,350	85	103	69	85	92	9,500	31.7
Manganese[c] (µg/L)	**1,380**[f]	29	494	347	124	6	8	4	1,380	27.6
Carbon tetrachloride (µg/L)	NA-	NA	880	570	NA	NA	NA	**1600**	1600	320
Fluoride (µg/L)	3,400	1,000	2700	231	1,600	2,700	2,600	4900	9,800	2.4
pH	[7.61, **9.99**]	[**7.08**, 8.44]	[7.65, 8.23]	[7.55, 7.90]	[7.85, 8.01]	[7.81, 7.89]	[7.68, 7.75]	[7.95, 8.31]	[7.08, 9.99]	Not Applicable

(a) Upgradient wells.
(b) Mid-field wells.
(c) Filtered sample results.
(d) Single sample collected during reporting period.
(e) Maximum across all network wells.
(f) Results are suspect because they are out of line with trends. Data are flagged as suspect but there is insufficient evidence to show whether the result is valid or invalid.

Note: All well numbers prefixed by 299-. < denotes analyte was not detected. NA = Not analyzed during reporting period.
Bold indicates well with maximum. MCL = Maximum contaminant level.

wells, particularly well 299-W11-24, also have had consistently higher iron and manganese concentrations and relatively lower chromium. In general, all of these indicate reducing conditions within or around the well. Also, there is a tendency within the vicinity of WMA T for nitrite to occur in detectable concentrations in wells sampling the tighter, upper portion of the aquifer suggesting that WMA T is a possible source for the nitrite.

In general, metals (iron, manganese, chromium) tend to be higher just after a well has been drilled and just before it goes dry. The high metals detected shortly after well completion may be a result of fine particulates left in the well as a result of construction, or it may be a result of temporary reducing conditions around the screened interval resulting from the exposure of fresh mineral surfaces by drilling activities. The higher concentration of metals detected as water levels in the well drop near the bottom of the screened interval most likely are a result of very fine particulates in the mud at the bottom of the well that can pass through the 0.45-micron filters normally used during sampling for metals. This latter explanation probably fits the high iron and manganese in well 299-W11-24, which had less than one meter of water in the well when the sample was taken.

The sample with elevated gross alpha, 98 pCi/L in well 299-W11-27, was a highly turbid, unfiltered sample taken late in the life of the well. Probably, the high gross alpha levels represent contaminants sorbed on particulates in the well bottom and not dissolved in groundwater. The nearest well to 299-W11-27 is its replacement well 299-W10-24, which does not have a history of elevated gross alpha.

6.0 Conceptual Model

An updated conceptual model of processes controlling the rate and extent of contaminant distribution in groundwater in the vicinity of the Waste Management Area T must include the following:

- Complex contaminant plume interactions and concentration-time patterns are due to changes in past disposal practices resulting in changing flow directions and a long-term decline in the water table.
- Vertical and horizontal changes in lithology result in spatial variations in aquifer properties which, in turn, result in vertical and horizontal variations in contaminant distribution patterns.
- Vertical and horizontal changes in lithology are local and occur over distances of 30 meters or less.
- Low aquifer permeability in the upper part of the unconfined aquifer in some wells results in slow groundwater flow rates and contaminant plumes that move on the order of 3 to 9 meters per year.
- Past-practice disposal of large volumes of wastewater upgradient of WMA T accounts for most of the deeply distributed contaminants (CCl_4, nitrate, tritium, chromium).

Additional details concerning these processes and proposed explanations for observed contaminant distribution patterns are discussed in the following sections.

6.1 Aquifer Properties

The permeability of the upper portion of the aquifer at WMA T is highly variable. This variability is attributed to changes in lithology, including silt content and cementation, within the aquifer sediments. These lithologic changes result in permeability changes that are highly variable both laterally and in thickness. In some wells, such as 299-W11-39, the entire (or most) of the 10.7-meter screen lengths are in a low permeable zone. Other wells, such as 299-W10-24 and 299-W11-42 at WMA T, have screened intervals that penetrate into a deeper, more permeable zone and, in still other wells (299-W10-28), the entire screened interval appears to be in a highly permeable zone. The water chemistry in the different zones appears to be different. The chemical characteristics of the deeper zone are similar to groundwater sampled south and east of WMA T and are considered to be a regional background.

The groundwater flow direction at WMA T is currently easterly. Aquifer tests and data derived from aquifer tests indicate groundwater flow rates are on the order of 0.02 to 0.03 meters per day.

6.2 Contaminants at WMA T

The contaminant plume at WMA T was initially detected in well 299-W11-27 at the northeastern corner of the WMA in late 1995. The first appearance of the contaminants at well 299-W11-27 corresponded to the cessation of liquid discharges to ground in the 200 West Area. Tritium/technetium-99 concentration ratios indicate that the plume was present at this location for several years prior to 1995, but was masked by dilution with surface water. The most reasonable source of surface water is the 60.9 centimeter, non-pressurized, vitrified clay pipe located several meters from the well. The mechanical shock and vibration produced by cable tool drilling may have caused damage to the rather brittle pipe and resulted in a significant water leak. The pipe carried T Plant effluent, mostly cooling water, from the 207-T retention basin to the 216-T-4-2 ditch.

The *Atomic Energy Act*-regulated technetium-99 plume described above, when first detected, was migrating toward the northeast. Because there is no apparent upgradient source, and due to the apparent narrowness of the plume, its origin is attributed to WMA T. Technetium-99 concentrations indicate that, at least at well 299-W10-24, the contaminant is located in a less permeable zone near the water table. After the 1997 to 1998 change in groundwater flow direction, the plume was detected in well 299-W11-23, located to the east of well 299-W11-27 and is presently being detected (4,000 to 5,000 pCi/L of technetium-99) in replacement well 299-W11-39. Apparently, the original plume was smeared in a southwest to northeast direction and the resulting elongate plume is moving easterly across the northeast corner of the WMA.

The low hydraulic conductivities and flow velocities measured in the top of the aquifer, in places, imply that the plume, contained within that zone, must be relatively restricted in areal extent. The major uncertainty is the extent of this low permeability zone and the degree to which the plume is entering the more permeable portions of the aquifer. It is important to keep in mind that although 21,700 pCi/L was the highest technetium-99 concentration detected in well 299-W11-27, there is no reason to assume that it represents the highest concentration in the plume. Alternatively, if the plume is slowly draining into the more conductive zone at depth at a rate greater than or equal to any contaminant drainage from the vadose zone into the groundwater, higher contaminant concentration would not be expected.

A second uncertainty stems from the lack of knowledge about the contaminant source within the WMA. Several potential sources exist within WMA T; chief among them is tank T-106. Tank T-106 leaked approximately 435,300 liters of tank waste in 1973 (Hanlon 2001). A second, less probable possibility is tank T-101, which leaked about 28,400 liters in 1992. Modeling indicates that when breakthrough of a major vadose zone plume occurs, drainage may continue for a number of years (Reidel et al. 1993). If the source within the WMA is still continuing to drain to groundwater, a re-organized plume will be forming and migrating eastward under the current groundwater flow regime.

7.0 Conclusions

Additional assessment characterization and monitoring activities were conducted to evaluate the rate, extent, and concentration of contaminants in groundwater beneath WMA T. Installation of additional groundwater monitoring wells, hydrologic testing, and sampling and analysis (both vertically and spatially) also provided new information, which resulted in the following conclusions.

7.1 Rate and Extent of Contaminant Migration

As a result of the vertical variability in aquifer properties and in the distribution of contaminants, there appears to be two flow zones, an upper low velocity zone and a lower zone with higher flow rates. Variable, vertical and horizontal zones of differing permeability typify the upper part of the aquifer at WMA T. Measurements made in well 299-W10-24 indicate variations of more than an order of magnitude within the screened interval of the well. Also, drawdown data from development pumping suggests large differences in the aquifer's hydraulic conductivity across the WMA.

Deep drilling at WMA T (well 299-W10-24) indicates the presence of *Atomic Energy Act*-regulated tritium and technetium-99, EPA-regulated nitrate, and RCRA-regulated carbon tetrachloride throughout the thickness of the unconfined aquifer and below the lower mud unit of the Ringold Formation. Maximum concentrations for tritium, nitrate, and carbon tetrachloride at WMA T occur at depths of 15 to 40 meters below the water table. These concentrations are a result of past-practice waste disposal to cribs and trenches.

Sampling during drilling and comparisons between adjacent wells indicates considerable chemical variability within the upper portion (upper 10 to 12 meters) of the aquifer. Variability at WMA T is largely a result of hydraulic conductivity variation in this portion of the aquifer.

The tank farm contaminant plume detected at the northeastern corner of WMA T appears to be restricted to the upper part of the aquifer. This zone may have a low flow velocity. The deeper, higher flow rate zone, appears to be dominated by high sodium, high nitrate groundwater similar to the regional background. The tank farm contaminant plume was apparently present prior to 1995 but was masked by water leakage from a nearby water line. The plume was migrating toward the northeast prior to 1998. Since 1998, the existing plume has been moving laterally toward the east, under the new flow regime, and has been detected in wells 299-W11-23 and 299-W11-39.

Vadose zone characterization with wireline geophysical methods have shown the distribution of near surface contamination, which is probably the result of spills associated with tank farm operations, and deeper contamination, which probably resulted from tank leaks (GJO-99-101-TAR). Also, drilling results at WMA S-SX and various modeling studies (Johnson and Chou 2001; Knepp 2001) indicate that major vadose plumes within the tank farms may feed into groundwater for decades. Thus, it is likely that any vadose zone sources in the tank farm that are responsible for the contaminant plume detected in the northeastern corner of WMA T are still active. Given the uncertainty of the location of the sources, it is impossible to predict where these plumes may eventually emerge from the WMA under the new flow regimes.

7.2 Concentration of Contaminants

High concentrations of RCRA-regulated carbon tetrachloride and chromium, and EPA-regulated nitrate at WMA T are the result of a regional plume and not directly related to the WMA. *Atomic Energy Act*-regulated technetium-99, and some nitrate and chromium, are related to sources within the tank farms. The maximum technetium-99 concentrations reported in Chapter 5 are lower than the maximum concentrations reported by Hodges (1998); however, this does not necessarily indicate that those high concentrations have gone away. The highest concentrations in these plumes may not be intercepted by a well at this time.

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